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Application of geothermal energy for heating and fresh water production in a brackish water greenhouse desalination unit: A case study from Algeria

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ABSTRACT

The aim of this paper was to outline a proposed a new brackish water greenhouse desalination unit powered by geothermal energy for the development of arid and relatively cold regions, using Algeria as a case study. Countries which have abundant sea/brackish water resources and good geothermal conditions are ideal candidates for producing fresh water from sea/brackish water. The establishment of human habitats in these arid areas strongly depends on availability of fresh water. The main advantage of using geothermal energy to power brackish water greenhouse desalination units is that this renewable energy source can provide power 24 h a day. This resource is generally invariant with less intermittence problems compared to other renewable resources such as solar or wind energy. Geothermal resources can both be used to heat the greenhouses and to provide fresh water needed for irrigation of the crops cultivated inside the greenhouses. A review of the geothermal potential in the case study country is also outlined.

Contents

1. Introduction

In many countries that suffer a chronic shortage of water, such as those of the Middle East and North Africa (i.e. MENA), over 80% of all fresh water consumed is used for agriculture. As fresh water resources are finite, there is a relentless pressure to reduce agricultural use of water [1–4]. A possible solution to this dilemma is seawater greenhouse technology which employs humidification–dehumidification processes, and provides growing environment that substantially reduces the amount of water required for irrigation. In addition it provides a source of fresh water from seawater or brackish water [2,3,5].

By its geographical location in an arid and semi-arid region, the MENA country of Algeria has been subjected to unfavorable physical and hydro-climatic conditions accentuated by periods of chronic dryness. The climatic change which has prevailed for several decades in North Africa has touched this region in

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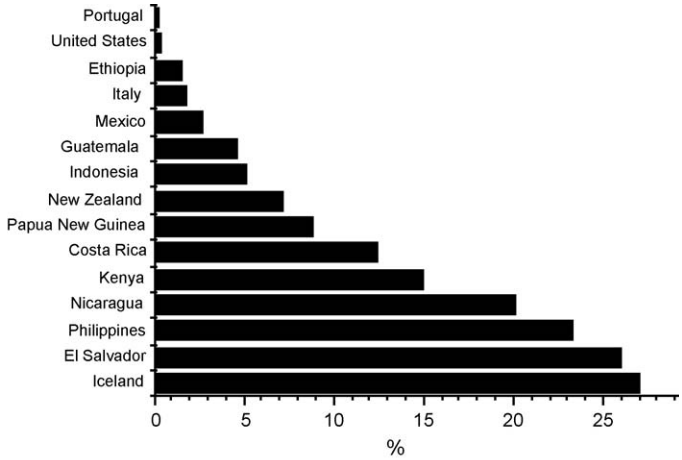


Fig. 1. Share of total electricity generation from geothermal resources in top 15 countries [8].

particular and has had a negative impact on its water resources. The district receives low quantities of rain. Inherently, the available water resources in the case study country, for example, are rather modest in terms of both quantity and quality and the use of water for irrigation represents more than 55% of the total fresh water consumed and is increasing [6].

The greenhouse is a versatile system that can be adapted for water desalination [2,3,5]. This has several advantages such as flexibility in capacity, moderate installation and operating costs, simplicity, possibility of using low temperature and the use of renewable energy (e.g. solar, geothermal, recovered energy or cogeneration). In a recent study by Mahmoudi et al. [7], it was demonstrated that wind energy can power brackish water desalination units in southern Algeria.

Geothermal energy has great potential in greenhouse desalination technology. The former can be used for electricity production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating through geothermal heat pumps. Currently, 24 countries are involved in the generation of electricity using geothermal resources. More than 10,000 megawatts are produced which meet the needs of 60 million people [8]. Iceland is widely considered the role model of the geothermal community. This country of just over 300,000 people is actually fully powered by renewable forms of energy, with 27% of the electricity and 87% of the heating needs provided by geothermal energy [8]. Fig. 1 represents the percentage of total electricity generation from geothermal resources in the top 15 countries.

The aims of the current paper were to provide an overview of desalination using renewable energies, assess geothermal desalination, consider geothermal resources in the case study region, present an overview of seawater greenhouse technology, and give an analysis and assessment of the advantages of using geothermal sources to power the brackish water greenhouse desalination in cold regions.

2. Overview of desalination using renewable energies

Many possible combinations can be envisaged between renewable energy sources such as wind, solar and geothermal, and desalination technologies [9]. The forms of energy which can be obtained from renewable energy sources are solar/thermal, mechanical and electrical. Renewable energies such as solar and wind have application in desalination technology. A variety of solar desalination devices, for example, have been developed [10]. One of the more successful ones for instance is the multiple-effect still. Latent heat of condensation is recovered, in two or more stages (generally referred to as multi-effects), so as to increase production of distillate water and improve system efficiency. It has become apparent that a key feature in improving overall thermal efficiency is the need to gain a better understanding of the thermodynamics behind the multiple use of the latent heat of condensation within a multi-effect humidification–dehumidification process [10]. In addition, while a system may be technically very efficient it may not be economic (i.e. the cost of water production may be too high) [11]. Therefore, both efficiency and economics need to be considered when choosing a solar desalination scheme.

The coupling of wind/solar energy and desalination systems holds great promise for increasing water supplies in arid regions [3,7]. An effective integration of these technologies will allow countries to address water shortage problems with a domestic energy source that does not produce air pollution or contribute to the global problem of climate change. Meanwhile the costs of desalination and renewable energy systems are steadily decreasing, while fuel prices are rising and fuel supplies are decreasing.

The desalination units powered by renewable energy systems are uniquely suited to provide water and electricity in remote areas where water and electricity infrastructures are currently lacking. The study of the potential interface between desalination and renewable energy technologies has increased significantly in the last five years. Considering that the energy requirements for desalination continues to be a highly influential factor in system costs, the integration of renewable energy systems with desalination seems to be a natural and strategic coupling of technologies [12].

The southern part of the case study country of Algeria, comprising more than 90% of the total land area, is the great expanse of the Sahara Desert. While this region is rich in groundwater sources, it is often brackish in nature and thus unsuitable for drinking or irrigation. A large percentage of these waters need to be desalted before they can be exploited [3,7].

The amalgamation of renewable resources in desalination and water purification is becoming increasingly attractive especially for remote and rural areas where small quantities of water are needed. This is justified by the fact that areas of fresh water shortages in Algeria have plenty of solar [13] and wind energy [7], and also contain important geothermal reservoirs [14]. A survey of these sources showed that in any part of the country at least one or more sources of renewable energy are readily available (Table 1). Solar energy in particular is present over the entire state. The most investigated form of combination between renewable energy sources and desalination processes is the use of direct sun energy to produce fresh water in a solar still.

3. Assessment of geothermal desalination

Brackish water desalination is one of the most promising fields for the application of geothermal energy. When using geothermal energy to power desalination plants, thermal storage problems are avoided, also the energy output of this resource is generally stable compared to other renewable resources such as solar and wind energy [15].

Kalogirou [16] showed that the ground temperature below a certain depth remains relatively constant throughout the year. Popiel et al. [17] reported on the temperature distribution measured in the ground during a two-year period. They concluded that one can distinguish three ground zones; surface, shallow and deep. Hence, geothermal energy sources can be classified in terms of their measured temperatures as low ($<$100 °C), medium (100–150 °C) and high ($>$150 °C).

Geothermal wells deeper than 100 m can be employed to power desalination plants [16]. The geothermal energy would be used to heat the saline water and or it could be used to generate electricity for operating reverse osmosis units. Ophir [18] presented an

Table 1
Renewable energy sources (RES) desalination combinations (adapted from [27]).

Renewable energy sources technology	Feed water	Desalting technologies				
		Multiple-effect boiling (MEB)	Multi-stage flash (MSF)	Reverse osmosis (RO)	Electrodialysis (ED)	Compression (MVC)
Solar thermal	Seawater	⅄	⅄			
Photovoltaic	Seawater			⅄		
	Brackish water			⅄	⅄	
Wind	Seawater			⅄		⅄
	Brackish water			⅄		
Geothermal	Seawater	⅄				

economic study of a desalination plant powered by a geothermal source of 110–130 °C. Another technical and economic study was conducted by Karytsas [19,20] to analyze the feasibility of using geothermal resources between 75 and 90 °C to power a multiple-effect boiling system (MEB).

Bourouni et al. [21,22] reported on two geothermal-powered distillation plants, the first in France [21] and the second in Tunisia [22]. The two installations based on humidification–dehumidification used evaporators and condensers made of polypropylene and operated at a temperature between 60 and 90 °C. Bouchekima [13] reported a study on a solar still installed in southern Algeria, where the feed was brackish underground geothermal water.

The utilization of geothermal power can also be envisaged as a direct stream power in thermal desalination plants. Furthermore, with the recent progress on membranes distillation technology, the utilization of geothermal brine with temperature up to 60 °C has become a promising option [23].

Desalination by means of renewable energy sources is thus a suitable solution for providing fresh water to a number of regions in the Mediterranean Basin and especially in Algeria. This solution becomes more and more competitive especially for remote and rural areas where lower quantities of water are needed.

4. Geothermal resources in the case study region

Algeria is an oil and gas producer; hence decision makers believed that encouraging using renewable energies can help to conserve the country's oil resources [24]. The case study country is also Africa's second-largest nation and the eleventh in the word in terms of land area. It is bordered in the north by 1200 km of Mediterranean coastline. Among the major challenges facing the region in the incoming 10-years are water and energy resources as well as risk management of the environment [24,25]. We can speculate that due to the interdependence of the world's economies and decreasing oil and gas reserves, decision makers will need to review their policies regarding the promotion of renewable energies.

Geothermal energy represents one of the most significant sources of renewable energies. In the case study area two major structural units divided by the South Atlas Fault (Fig. 2); with Alpine Algeria (or Northern Algeria) in the north and the Saharan Platform in the south. The northern region is formed by the Tellian Atlas, the High Plains and the Saharian Atlas (Fig. 3). This part is characterized by an irregular distribution of its geothermal reservoirs. The Tellian nappes constitute the main geothermal reservoirs. Hot ground water is generally at neutral pH, total dissolved salts (TDS) range from 0.4 to 10 g/l and can reach a temperature in the range of 22–98 °C [14].

The southern region formed by the northern Sahara is characterized by a geothermal aquifer which is commonly named 'Albian reservoir' (Fig. 4). The basin extends to Libya and Tunisia in the east and covers a total land surface of 1 million km^2. This part of Algeria is estimated at 700,000 km^2 and contains approximately 40 trillion m^3 of brackish groundwater water. The depth of the reservoir varies between 200 m in the west to more than 1000 m in the east. Deeper wells can provide water at 50–60 °C temperature, 100–400 L/s flow rate and average TDS (total dissolved solids) of 2 g/L [6].

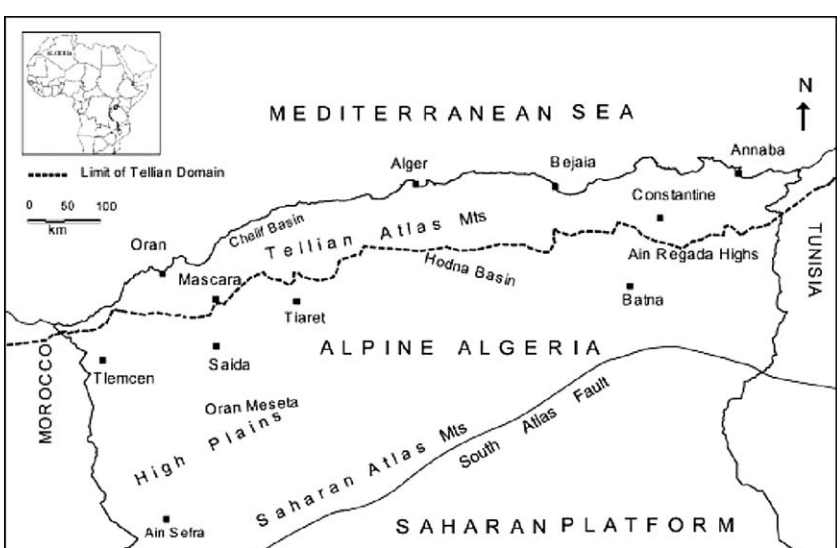


Fig. 2. Geological units of Northern Algeria [28].

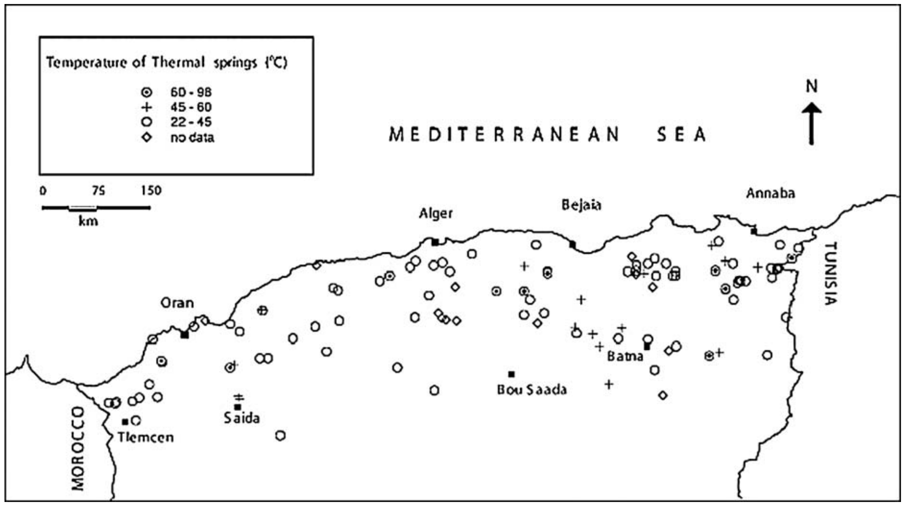


Fig. 3. Main thermal springs in northern Algeria [28].

In 1988, an ambitious program was established by the government [14] with the aim to expand the utilization of geothermal heated greenhouses in regions affected by frost (i.e. highlands and some localities in the south) and other sites, such as Hammam Meskhoutine (east Algeria), Touggourt and Ghardaia (southern region). Unfortunately, this program was cancelled due to security concerns. In the last decade, effort has been directed to exploit the numerous thermal springs of the north and the hot water wells of the Saharian reservoir. More than 900 MWt is expected to be produced in the future [14].

5. Seawater greenhouse technology

The sea/brackish water greenhouse desalination process is a new development that offers sustainable solution to the problem of providing water for agriculture in arid regions where brackish and/or seawater are available. The original process uses seawater to cool and humidify the air that ventilates the greenhouse. Fresh water is condensed out of the humid air. This enables the year round cultivation of high value crops that would otherwise be difficult or impossible to grow in hot, arid regions.

The innovative idea of the seawater greenhouse was developed by Paton and Davies [2]. The first pilot was built and tested in the Canary Island of Tenerife in 1992 (Fig. 5a). Once known as the 'Garden of the Gods', but now the island is arid and gravely damaged by excessive abstraction of ground water [2]. The early results were promising and demonstrated the possibility to develop the technology in other arid regions. A modified and improved seawater greenhouse was constructed on Al-Aryam Island of Abu Dhabi in the United Arab Emirates in 2000 (Fig. 5b) [26]. For both pilot studies the production of crops was excellent, and fresh water was successfully produced for the greenhouse

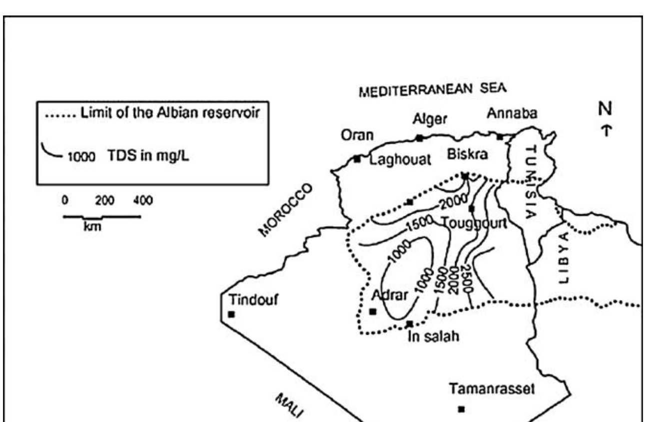


Fig. 4. Distribution of total dissolved solid concentrations (TDS) in well waters from the Albian reservoir (in mg/L) in Southern Algeria [28].

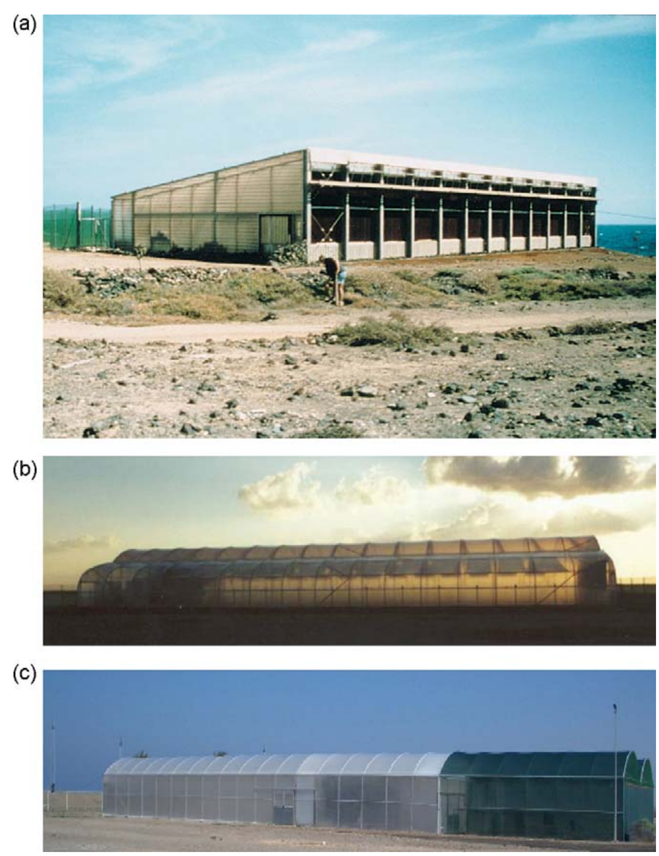


Fig. 5. (a) The seawater greenhouse in Tenerife, Canary Island, 1992 [29]. (b) Seawater greenhouse constructed on Al-Aryam Island, Abu Dhabi, United Arab Emirates, 2000 [29]. (c) The seawater greenhouse at Al-Hail, Muscat in the Sultanate of Oman, 2004 [3].

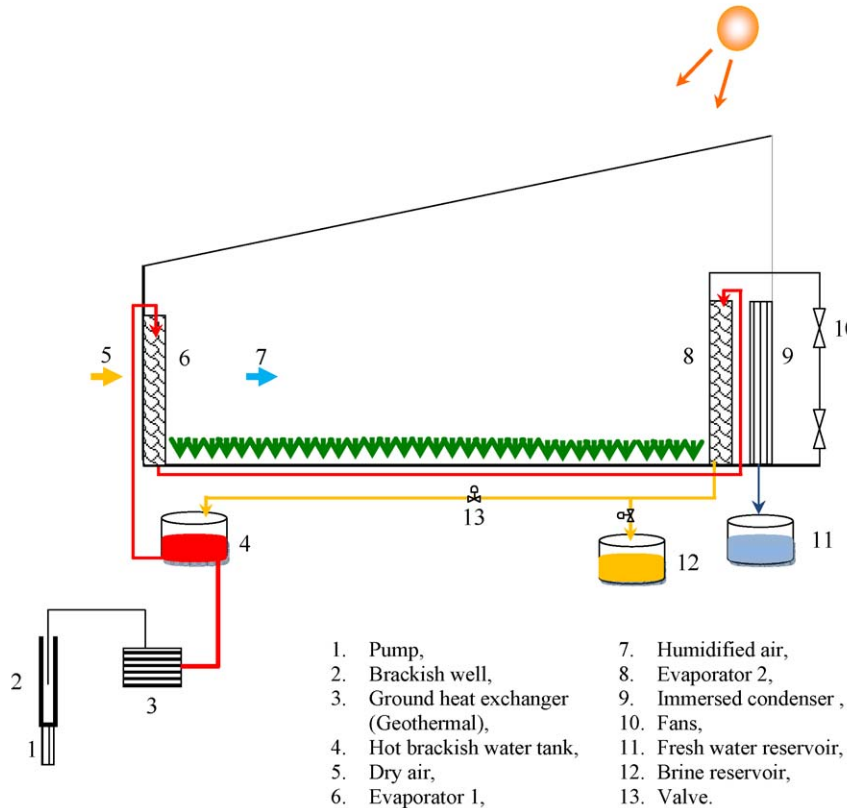


Fig. 6. Process schematic.

irrigation proposes. In 2004 a new pilot seawater greenhouse was built near Muscat in Oman (Fig. 5c) [3]. The aim of the project was to demonstrate the technology to local farmers and organizations in the Arabian Gulf.

6. Application of geothermal sources to power brackish water greenhouse desalination in cold regions

The brackish water greenhouse desalination units are well suited for relatively cold regions affected by dryness but rich in geothermal brackish ground water [7] (Fig. 6). Geothermal energy is needed to heat the brackish water and to warm the greenhouse by means of the hot vapour leaving the first evaporator. It is important to note that if the greenhouse was to be built in arid and hot areas, geothermal energy would not be required. Instead, the traditional brackish water greenhouse described previously should be employed [3,7]. In this case the first evaporator acts to cool and humidify the air in the greenhouse.

In the current study, brackish water is pumped and filtered from a well and send into a ground heat exchanger (i.e. geothermal) to increase its temperature to an acceptable level. Generally these ground heat exchangers are made of a high-density polyethylene which is a tough plastic. This material is very durable, permits good heat exchange and is warranted for 50 years. Copper piping can also be used but this is more expensive than plastic [16]. Hot brackish water is fed in a cascade to the first evaporator then to the second evaporator. The brine water issued from the second evaporator is canalized to the brine tank. The brine can be circulated in the circuit several times until its concentration increases over an acceptable dissolved salt concentration. The concentrated brine is finally collected in a tank, where it is stored for later treatment or processing.

The evaporator is the entire front wall of the greenhouse structure. It consists of a cardboard honeycomb lattice and faces the prevailing wind [3]. Hot brackish water trickles down over this lattice, heating and humidifying the ambient cold air passing through into the planting area and contributing to the heating of the greenhouse. Fans draw the air through the greenhouse. Air passes through a second evaporator and is further humidified to saturation point. Air leaving the evaporator is nearly saturated and passes over the passive cooling system with a condenser (IC) immersed in a water basin. The fresh water condensing from the humid air is piped to storage for irrigation.

One advantage of using geothermal energy to power brackish water greenhouse desalination unit is that this natural resource can provide power 24 h a day. The renewable resource is generally invariant with less intermittence problems than for example wind or solar energy. The use of geothermal energy makes the proposed greenhouse design unique by allowing for warm water to trickle down the evaporators, this increasing the rate of evaporation and thus the vapor content of the air inside the greenhouse. This should improve fresh water production and thus thermodynamic and economic efficiency.

7. Concluding remarks

The world's water demands are rising considerably. Much research has been directed at addressing the challenges in using renewable energy to meet the power needs for desalination plants. This study has analyzed the feasibility of using geothermal energy to power brackish water greenhouse desalination units for the development of arid and relatively cool regions of the case study country of Algeria.

There are numerous benefits for the growth of the humidification–dehumidification seawater greenhouse system in arid regions. This technology can also provide extra water supplies for other purposes such as the development of environmental projects. In addition, it gives the opportunity to develop a high

value agricultural sector that is sustainable in the long term and immune to climatic variations.

Wind, solar and geothermal renewable technologies are rapidly emerging with the promise of economic and environmental viability for desalination. There is a need to accelerate the development of novel water production systems from renewable energies. These technologies will help to reduce environmental concerns.

In closing, this analysis has shown that there is great potential for the use of geothermal energy in many parts of the case study region. Geothermal sources could provide a viable source of energy to power the brackish water greenhouse desalination units which can help in the development of the area. Finally, it must be noted that part of the solution to the world's water shortage is not only to produce more water, but also to use less of it. The need for integrated solutions to the scarce fresh water resources problem is one of the challenges facing mankind.

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